

Estimation of uncertainties in CT metrology by simulation

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Estimation of uncertainties in CT metrology by simulation

CT Audit University of Padova, October 26th

Jochen Hiller

 $f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^{i}}{i!} f^{(i)}(x) = a^{b} + 2 \int a^{b} e^{i\pi} = \frac{1}{2} [2.7182818284] + 2 \int a^{2} e^{i\pi} = \frac{1}{2} [2.71828184] + 2 \int a^{2} e^{i\pi} = \frac{1}{2} [2.7182818284] + 2 \int a^{2} e^{i\pi} = \frac{1}{2} [2.71828184] + 2 \int a^{2} e^{i\pi} = \frac{1}{2} [2.71848184] + 2 \int a^{2} e^{i\pi} = \frac{1}{2} [2.7184814] + 2 \int a^{2}$

DTU Mechanical Engineering

Department of Mechanical Engineering

Motivation and problem definition

- The proposed approach
- Modelling and analytical simulation of CT scanning process
- Case study: Uncertainty estimation at a simple workpiece
- Summary and outlook

Motivation and problem definition







Influences lead to systematic and random measurement errors

Motivation and problem definition





Ø: 2,424 mm ± ???

Analytical calculation

almost not possible in CT

Experimental method

- calibrated workpiece available?
- Destruction of the workpiece?
- repeated measurements (time-factor)

Simulation method

- "virtual experiments" using computers
- numerical evaluation of measurement uncertainty
- Basis: Monte Carlo method (MCM)

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Projection

CT model

Consideration of

- Image unsharpness
- Image noise
- Image artefacts (beamhardening, scatter radiation)
- System misalignment including temporal focus drift
- Environment influences (temperature)
- Random variability of input quantities





Tomolibri[®] Micro-CT system



Relevant information

- Focal spot size
- Focus drift (in 3 dimensions if possible)
- Detector contrast & noise transmission
- System misalignment parameters





First validation of synthetic projection images using simple test objects like step-wedges





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Material: X20Cr13 (Steel)

Measuring tasks:

- Evaluation of the 3 cylinder diameters
- Evaluation of associated form deviations of the cylindrical geometries









Result of dimensional CT measurements:

Geometry element	Diameter in mm	Form deviation in µm	
Outer cylinder, small	8,014	8	
Outer cylinder, big	9,812	9	
Inner cylinder	6,192	21	



Stochastic variation of input parameter values



	Parameter	Default	Uncertainty	Range of values	
e	U _R I _R	200 0,1	1 % 5 %	198202 0,0950,105	Uniform distributed
tub	$\begin{array}{c} \alpha_{\mathrm{T}} \\ B_{\mathrm{h}} \end{array}$	15,0 54,0	33,3 % 5 %	51,356,7	input quantities
ray	$B_{\rm v}$ $D_{{ m h}_1}$	50,0 $8,45 \cdot 10^{-3}$	5% 42,0%	47,552,5 $(4,912,0) \cdot 10^{-3}$	assumed
×	D_{h_2} D_{v_1}	2,85 $4,03 \cdot 10^{-3}$ 1.95	19,3 % 20 % 18 %	2,33,4 $(3,24,8) \cdot 10^{-3}$ 1.6 2.3	
ر ح (Δx_{det} Δy_{det}	0,0 0,0	0,2 Pixel 0,2 Pixel	$-40,0\ldots 40,0$ $-40,0\ldots 40,0$	- U _{ct}
omet 人	$\eta_{ m det} \ \phi_{ m det} \ heta_{ m det}$	0,0 0,0 0,0	0,1° 1,0° 0,5°	$-0,1\ldots 0,1$ $-1,0\ldots 1,0$ $-0,5\ldots 0,5$	
Ŭ Ŭ	FDA FOA	1539,447 114,953	1 % 0,3 %	1524,0521554,841 114,608115,298	
Position	$ \begin{bmatrix} T_x \\ T_y \end{bmatrix} $	0,0 0,0	0,5 mm 0,5 mm	$-0,5\dots 0,5 \\ -0,5\dots 0,5$	Number of simulations
	$T_z R_x$	0,0 0,0	0,5 mm 1,5°	-0,50,5 -1,51,5) M = 50

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Result:

$$U = U_{\rm sim} = U_{\rm ct}$$

If uncertainty contribution u₁...u_i from other sources avaliable (hybrid):

$$U = k \cdot \sqrt{u_1^2 + \ldots + u_i^2 + u_{ ext{sim}}^2}$$
 with $u_{ ext{sim}} = rac{U_{ ext{sim}}}{k}$

• If uncertainty contribution $u_{sim_1}...u_{sim_j}$ from simulation can be seperated \rightarrow no correlations among single contributions $u_{sim_1}...u_{sim}$:

$$U = k \cdot \sqrt{u_1^2 + \ldots + u_i^2 + u_{\sin_1}^2 + \ldots + u_{\sin_j}^2}$$

Completed result:

$$Y = y \pm U$$

Diameter:

Geometry element	<i>U</i> (95 %) in mm	<i>U</i> (99 %) in mm	Y (95 %) in mm	Y (99 %) in mm
Outer cylinder, small	0,080	0,086	$\textbf{8,014} \pm \textbf{0,080}$	$\textbf{8,014} \pm \textbf{0,086}$
Outer cylinder, big	0,102	0,108	9,812 ± 0,102	$9{,}812\pm0{,}108$
Inner cylinder	0,064	0,066	$\textbf{6,192} \pm \textbf{0,064}$	$\textbf{6,192} \pm \textbf{0,066}$

Form deviation:

Geometry element	<i>U</i> (95 %) in μm	<i>U</i> (99 %) in in μm	Υ (95 %) in μm	Υ (99 %) in μm
Outer cylinder, small	3	3	8 ± 3	8 ± 3
Outer cylinder, big	4	4	9 ± 4	9 ± 4
Inner cylinder	6	9	21 ± 6	21 ± 9

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Summary and outlook



A simulation-based method to estimate uncertainties in dimensional CT using synthetic X-ray projection data and the Monte Carlo method, combined in the virtual CT, was presented

Further developments should be concentrated on:

- Increasing of computational performance to increase the number of simulations
- Development of systematic workflow for characterization of a CT system to adapt the simulation enviroment
- Minimization of input quantities to the most significant ones and studying of correlations
- Development of procedures to validate CT simulators in 2D/3D





Test of plausibility according to VDI/VDE 2617-7

using calibrated workpieces:





Thank you for your attention